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THE DEVELOPMENT OF VAPOUR CONTAINMENT SYSTEMS AND THEIR DEPLOYMENT DURING OPERATION ABBOTT: A UXO CLEARANCE OF FIRED CONVENTIONAL AND CHEMICAL MUNITIONS IN THE UK(U)

by
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Abstract

The problem of buried CW munitions occurs throughout the world. Large numbers were sea dumped or abandoned on land at the end of both world wars and present a continuing hazard to this day. Many of these burial sites are now of safety or environmental concern, or are required for development, and are being cleared. During such UXO clearance operations of buried CW munitions a potentially severe hazard exists to operators and/or members of the public from CW agent released due to leaks or detonation. The development and testing of a cheap, robust and field portable vapour containment system (VCS) is described. The practical problems of deploying the system during OPERATION ABBOTT, a major UXO clearance of a pre W.W.II firing range of mixed conventional and CW munitions in the UK are then discussed.

Biography

Dr Richard Soilleux is Technical Manager for Chemical Weapons (CW) Demilitarisation and works for the United Kingdom Defence Evaluation and Research Agency (DERA). He has had more than 25 years experience in Chemical Defence research and has a wide knowledge of global CW demilitarisation issues.

1 Introduction

1.1 The recovery of old buried Chemical Warfare (CW) munitions is a difficult and dangerous process with combined explosive and chemical hazards. Of particular concern during Explosive Ordnance Disposal (EOD) operations involving these munitions is the large downwind hazard to nearby populations that would arise from an instantaneous release of non-persistent CW agents, especially, phosgene or chlorine.

1.2 This concern was discussed during 1994 during the planning stage of a major clearance operation of CW munitions from a former Army Training Area in the UK. A possible technical solution to the problem was identified in early 1995, and the necessary equipment designed, procured and tested at DERA Porton Down. The trials were designed principally to demonstrate that such a containment system would provide sufficient protection to enable CW munitions to be recovered safely in public areas in a manner that would generate public confidence.

1.3 Following the success of the clearance operation, further developments have taken place, mainly to test the addition of ballistic containment to the vapour containment demonstrated in the early trials. This paper describes tests carried out to demonstrate the possibility of providing protection against the release of CW agent vapour and fragmentation from the accidental detonation of a single munition, or one which has to be deliberately detonated *in situ*, thus causing a fragmentation and vapour hazard. The Vapour Containment System (VCS) tested consists of a portable tent fitted with Air Filtration Units (AFUs) to absorb any escaping gases. Tests using an inner foam filled enclosure consisting of multiple layers of ballistic nylon are also described. Finally, the practicalities are discussed of deploying the VCS during OPERATION ABBOT, a recent major UK clearance of pre WWII chemical UXO.

2 Equipment

2.1 Munition simulation

2.1.1 The munition type selected to be simulated for this trial was the livens projector. This is a British designed World War 1 (WWI) chemical munition which was selected because it carries a larger payload of volatile chemical agent than most other UK chemical munitions. The functioning of such a munition charged with a volatile CW agent such as chlorine or phosgene therefore represents the worst case which was to be expected during CW clearance operations in the UK. Consequently, if the vapour containment is successful with a bursting livens projector then it should provide protection against most other types of chemical munitions likely to be encountered.

2.1.2 Steel cylinders containing chlorine were also used as simulated munitions. For the first tests it was thought advisable on safety grounds to use the less toxic WW1 CW agent chlorine rather than phosgene especially as the close physical and chemical properties of the two agents meant that results obtained for chlorine would be readily applicable to phosgene. Phosgene was the standard fill for livens projectors so the final test used a refurbished munition filled with this agent. The central burster tube was filled with PE 4 equivalent in explosive power to the original. (NB This was done before the Chemical Weapons Convention (CWC) entered into force and there were no legal constraints on trials involving the refurbishment of old CW munitions.).

2.2 Vapour containment

2.2.1 Two sizes of VCS were procured and trialed during the initial tests, a small man portable system and a large, transportable structure based on a commercially available unit.

Small VCS

2.2.2 The small VCS was intended to be used for small excavations likely to contain only one or two items of ordnance, or as a packing/re-packing facility for single munitions. It consisted of a Polyethylene split film cover mounted on a standard Service Issue 12' x 12' aluminium frame and was connected to four 200cfm Air Filtration Units (AFUs) such that air is drawn from within the VCS and through the charcoal filter before being discharged to the atmosphere.

2.2.3 The cover of the VCS was constructed with gussets which, in the event of a rapid release of vapour, would expand, increasing the volume of the structure by approximately 25%, ie an additional 5 m^3 of gas calculated to be released from the livens projector. In this way, the vapour would remain within the VCS and be subsequently absorbed onto the charcoal filter. (A VCS based on this trial design is now available commercially from Howden Air Control in the UK.)

Large VCS

2.2.4 The large VCS was based on a commercially available 20 m x 24 m Rubb Shelter. This comprised a steel frame which is partly assembled on the ground and then raised into position using winches. The height of the assembled enclosure was approximately 12 metres. The volume of the large VCS was approximately 5,760 m^3 of which the 5 m^3 expected to be released by the livens represents less than 0.1% so that additional pleating to accommodate this extra volume was not considered necessary. The frame was clad with a PVC coated polyester outer envelope, backed by a polypropylene split film inner liner and the enclosure walls fitted with 10 ports on each side to allow the connection of up to twenty 200cfm Collective Protection fan/filter units. It was found preferable to locate the 10 AFUs required to give the necessary ventilation rate along one side leaving the other side completely clear.

AFUs

2.2.5 The standard portable NBC filtration units AFUs used by British Forces for un-hardened collective protection were used to provide a slight negative pressure inside the VCS and at the same time remove the agent from the vapour containment system. The airflow through each AFU was 200 cfm^{-1}.

2.3.2 **Primary ballistic containment**

2.3.2.1 The ballistic containment system (BCS) consisted of a metal frame (69 ft^3) covered by four blankets each constructed from four layers of ballistic nylon.

2.3.2.2 The BCS was filled with Stabilised Aqueous Foam Concentrate, AFC-380 mixed with water. This was supplied by Sanitek Products Inc.

2.3.3 Sound/and Blast Effects

7.4.1.1 Four window frames were positioned on the trial site as a simple experiment to demonstrate that the blast from a livens within the BCS, would be insufficient to damage the windows of houses, in the vicinity. Two of the window frames were positioned approximately 25 m (82 ft) and two, 50 m (164 ft) from the detonation point.

7.4.1.2 Six Bruel & Kjaer 22231 M noise meters were positioned near the VCS and window frames.

2.3.5 Sampling and analysis

2.3.5.1 Bubbler vapour samplers were used which are essentially glass U tubes containing a solvent which act as a vapour trap when air containing a soluble vapour is drawn, or bubbled, through them. After the trial the vapour absorbed in the bubbler solvent was extracted and analysed in the laboratory using gas chromatography. The equipment used was a Dionex DX100 ion chromatograph equipped with a conductivity detector.

2.3.5.2 A Mobile Infra Red Analyser (MIRAN) made by Foxboro in the US was used to measure in real time the very high gas concentrations expected inside the VCS. A second MIRAN was also used outside and downwind of the VCS.

2.3.5.3 An open path fourier transform infrared (OP-FTIR) spectrometer (manufactured by the Environmental Technology Group, Electro-Optics Division of Norcross, GA) was deployed to measure the downwind vapour hazard from the simulated chemical weapon detonation. This a stand-off chemical detector which functions by transmitting an infrared beam through the open air to a retro-reflector and then back to a receiver. If gases that absorb in the infrared are present in the beam, they can be identified and quantified.

2.4 Meteorological Station

2.4.1 A meteorological station, consisting of a 2m (6.56ft) anemometer, wind vane, and dry and wet bulb thermometers, was set up on the trial site to monitor wind speed, direction, temperature and humidity. Additional wind information was obtained from a 10m (32.81ft) anemometer and wind vane. Meteorological forecast information was also used for safety purposes.

3 Description of trials undertaken

3.1 Both the small and large VCS were evaluated to measure their containment efficiency. Three different scenarios representative of typical and "worst case" situations were be considered.

3.1.1 A slow leak from a punctured or corroded munition.

3.1.2 The instantaneous release of the contents of a munition, likely to have been caused either by the partial or incomplete functioning of the burster charge within the munition or by a large breach of the casing due to mechanical damage during excavation.

3.1.3 The instantaneous release of the contents of a munition combined with thrown metal fragments, as could be expected from a fully functioned burster charge within the munition.

3.1.4 In order to determine the effect of the detonation of a real Livens within a VCS, old empty munitions were filled with water and the central burster tubes loaded with sufficient explosive to simulate a complete munition. These were then detonated following placement in the trench within both types of VCS to allow the level of physical damage to be assessed and comparison made with earlier tests using simulated munitions.

3.1.5 A final trial was carried out to test the effects of ballistic as well as vapour containment with a phosgene filled livens positioned in a trench covered by both a BCS and then a small VCS .

3.2 Trials of heat build-up in the VCS

3.2.1 Trials to measure the extent of heat build-up in both the large and small VCS were carried out very simply by taking measurements both inside and outside for a set period during the hottest part of the day. The effects of cooling were measured using commercial units switched on or off as appropriate.

4 Results and Discussion

4.1 VCS envelope performance

4.1.1 For the small VCS, the pleated cover design to accommodate temporarily large volumes of gas proved successful and the expansion prevented the fabric from rupturing and the structure from leaking allowing time for the AFUs to remove the excess gas.

4.1.2 It was assumed that the large VCS would easily contain the 5 m^3 of phosgene expected to be released. This assumption was borne out by experiment, visual and video recordings of the shelter during the explosive release of chlorine gas showed no evidence of fabric movement let alone the “bellying” that would be the result of significant gas overpressure.

4.1.3 The results from the two vapour samplers used in the trials within the small VCS show clear differences (a factor of 2) which is almost certainly due to the different concentrations of chlorine at the different sampling positions within the containment system.

4.1.4 In all experiments with both the small and large VCS, peak values for agent concentration were measured within the containment system, between 2 minutes and 5 minutes after release (peak concentrations in the small VCS averaged 252000 mg/m^3. The concentration then fell rapidly with respect to time over the sampling period which demonstrates rapid and efficient removal of the gaseous hazard by the AFUs. After 50 min concentrations were down to less than 2% of peak concentration. The conclusion that can be drawn from this is that after one hour the toxic vapour hazard was essentially eliminated.

4.1.5 The containment systems were visually inspected, the day following each trial when the residual gas had mostly dissipated, to see if they had been penetrated by fragments. There was clear evidence of fragment penetration in the envelope of the small VCS but the “rip-stop” material had functioned as planned and prevented any large tears forming. It was also noted that a discernible odour of chlorine was present, as the VCS was dismantled.

4.1.6 It was observed that the small VCS was virtually undamaged and could be re-used with minor refurbishment only whereas the large VCS showed no sign of damage at all.

4.2 AFU performance

Small VCS

4.2.1 In the case of the small VCS with the theoretically minimum number of AFUs filter breakthrough was noted on a number of occasions. In trials when chlorine was released slowly, no filter penetration was observed within the limits of detection. In trials which represented the greatest challenge to the small VCS, however, the samplers monitoring the outlet ducts of the AFUs, showed that chlorine was emitted from three out of the four AFUs. This indicates that the filter packs failed and the chlorine broke through.

4.2.2 The performance of the AFUs (used in the present role for which they were not designed) is clearly marginal if four only are used to absorb the contents of one livens projector. This is not unexpected, since the minimum number capable of dealing with this high level of challenge is four. Nevertheless, six AFUs would give a better performance and is recommended for any future versions of the AFU concept. Even better would be to design filtration systems specifically for this task.

Large VCS

4.2.3 With the large VCS, which was fitted with ten AFUs, there was no sign of filter breakthrough in either of the two trials carried out with the maximum challenge of chlorine gas. As in the case of the small VCS, however, all filters challenged by a release of a non persistent CW agent should be replaced regardless of any signs of breakthrough or over-heating.

4.3 Downwind samplers

7.4.1 No significant quantities of gas were measured at any of the downwind sample arrays during any of the trials although a trace of phosgene was detected by the OP-FTIR during the final trial. AFU changeover was extremely quick (<10s) and, although high concentrations were measured at the outlets of some units, total amounts released would have been small and rapidly diluted by atmospheric dispersion. The 2m wind was observed to always be towards the bubbler array during each trial, including both short and longer term variations in wind direction, and confirmed that any gas released would have been sampled.

4.4 Trials using ballistic and vapour containment

4.4.1 The inner BCS functioned as planned. The foam filling effectively reduced the power of the explosives to an extent that the Firing Officer expressed concern that the main explosive charge had failed to function. This was found not to be the case as the explosives functioned correctly and released the agent as intended. The BCS moved as a unit during the explosion, being displaced approximately 18 inches from the original position but remaining upright. The overpressure caused by the explosion was contained within the BCS to such an extent that effects on the VCS were negligible and the cover did not unfold.

4.4.2 The containment systems were visually inspected the following day to see if they had been penetrated by fragments. There was no evidence of fragment penetration in either the primary or the secondary containment systems although the primary system suffered some distortion of the metal framework, which was not sufficient to degrade the performance. The internal ballistic blankets were found to be heavily stained, probably as a result of the chemical reaction between the phosgene and the foam/water mixture.

4.4.4 It was observed that the secondary system was totally undamaged and could be re-used without refurbishment. The primary system would be re-usable, once the metal framework was straightened and the blankets washed.

4.5 Recommended safety distances

Small VCS

4.5.1 Safety distances have been calculated for use with the small VCS (without the BCS), under a variety of meteorological conditions. The civilian Health and Safety Executive standards for phosgene as detailed in EH40 have been used in the calculations and this publication allows a maximum short term exposure limit (STEL) of 0.25mg/m^3 for any15 min interval. Small, but detectable amounts of gas were identified downwind of the small VCS on a number of occasions and the calculations have been based on the worse case. In order to carry out the calculations, an estimated “source” 10m x 10m x 3m at a concentration of 15 mg/m^3 during a period of 20 min was used at the bubbler positions. Based on these values calculations have been made for a range of temperature wind speeds and meteorological stability categories. An example, calculated at 20 deg C and 4 m sec^{-1} wind speed, is shown in the following table.

Meteorological Stability	*Downwind safety distance*
Stable	850m
Neutral	216m
Unstable	125m

4.5.2 From this and a number of similar calculations, a downwind safety distance for the small VCS as configured in these trials has been determined as 1 km for use under all meteorological conditions, agent fills and most munition types. For munitions of greater capacity than a livens, such as large aircraft bombs, the small VCS is not appropriate and the large VCS should be used.

7.4.1 The 1 km safety distance is a considerable improvement on the figures for an un-contained phosgene filled livens which can be more than 20 km under the worst conditions. The effectiveness of the system is demonstrated by comparison of the above estimated “source” concentration of 15 mg/m^3 with the average peak concentration of 252,000 mg/m^3 for the explosive release trials ie a containment, or safety, factor of about 17,000. The single trial carried out with the BCS in place showed a peak concentration of about 250 times less due almost certainly to the reaction of phosgene with the aqueous foam. With additional development of the BCS/VCS concept, especially as regards the AFUs, it should be possible to reduce this safety factor still further.

Large VCS

4.5.4 The analytical results from the trials on the large VCS show that downwind levels of chlorine could not be distinguished from background levels. This means that at 15 m downwind where these measurements were taken, the concentration of any gas leaking from the structure in each of the trials was below measurable limits. A safety distance of at least 30m for unprotected personnel should be used, however, because it is possible that transient concentrations above these levels could exist close to any leakage points following an explosion. In practice, the explosive safety distance will be more than this and for convenience could be used for both types of hazard. The normal splinter safety distance of 50m is recommended with the large VCS.

4.6. Temperature trials

4.6.1 For the small VCS, the temperature inside depended markedly on the exterior meteorological conditions. Under still conditions, even with the cooling unit on, the temperature inside became unpleasantly hot, typically 10 degrees centigrade higher than the ambient temperature.

4.6.2 The cooling unit lowered the temperature inside the structure by some 2-3°C which is small but may be significant in very hot conditions. The dark green colour of the prototype being tested certainly contributed to the high internal temperatures and future envelopes should be made white or silver to reflect the maximum of solar radiation.

4.6.3 When the cooling unit inlets were laid at the head of the trench, one either side, this had the effect of rapidly displacing the air in the trench with cool and dry air. This approach was much more effective than trying to cool all the air in the VCS and since workers will often be in the trench excavating munitions, may be the most practical solution for many EOD tasks.

7.4.1 For the large VCS, it is clear that temperatures inside remained fairly constant and only 1-3°C above the outside air temperature. This would have been due to the large volume of air inside the structure and also because the white colour of the exterior fabric would have reflected much of the solar radiation.

4.7 Blast/Noise Damage Estimation During Ballistic Containment Test

4.7.1 Almost all (98.8%) of the fragments were found within the walls of the primary containment system. Some had obviously hit the inner surface and fallen to the ground within the BCS, others were located in the trench and some were found in the remnants of the sandbags which had covered the livens.

4.7.2 The maximum recorded sound level was 105dB. This was recorded by the meter which was positioned closest to the livens initiation point. These results show that the levels of sound recorded are well within the UK limit of 129 dB. This is the level where noise from military activities is found to be tolerated by the public (i.e. there are few complaints). It is therefore concluded that the noise level recorded during this trial is well below the level where a public nuisance would be caused.

4.7.3 The window frames were found to be undamaged after the trial and demonstrates that little, if any, structural damage would have been caused to nearby buildings.

5. The practicalities of using VCS during OP ABBOTT

5.1 Background

5.1.1 Op ABBOTT is a UXO clearance operation in the UK of a range containing chemical weapons which date back to the earliest days of chemical warfare. Close to Porton Down, the site was first acquired by the War Office in 1917 for the newly formed Trench Warfare Department which originally developed weapon systems including those which delivered CW. Latterly the site has been used for training exclusively in NBC defence.

5.1.2 In the 1917/1918 period a range was set up which was 2500 yards long. A variety of types of mortar were known to have been developed there including 3" Stokes, 4" Stokes, 6" Stokes, Livens projectors, 9.45" and 11" Trench Mortars.

5.1.3 Since chemical munitions were amongst the natures fired by these weapon systems and the range was experimental in nature from 1917 to the 1930s the existence of buried CW on the range is something which has been assumed throughout the operation.

5.1.4 The site is 130 ha, comprising a military training area and farmland. Not all of it is in the ownership of the Ministry of Defence.

5.2 Downwind hazards

5.2.1 The prevailing wind is normally from the South West and the area in question is in close proximity to two villages as well as being close to the Defence NBC Centre with its working accommodation and married quarters. There are thus significant numbers of unprotected people within 1500 m of the area being cleared.

5.2.2 Work has to be managed such that unprotected people, either those living nearby and others not directly involved in the recovery tasks are beyond the potentially hazardous area i.e. they are in a no effects zone. The worst possible CW incident was planned for, namely the instantaneous release of 15 kg of phosgene from a livens projector.

5.2.3 This is the rationale that lead to the decision to deploy VCS during the operation to reduce the potentially hazardous distances to those from which unprotected people can be excluded.

5.3 Practicalities of VCS deployment

5.3.1 It was decided that the small VCS only would be deployed during Operation ABBOT since it had been demonstrated to be effective against the largest type of CW munition likely to be encountered. It had also been demonstrated during other small scale operations that the small VCS could easily be moved into position manually provided that the AFUs could be moved and positioned using a forklift truck. It was also decided not to use the BCS since safety distances were such that ample protection would be provided for the public without this additional layer of containment. There was also considerable concern by the Army EOD operators that the additional logistic burden of deploying the BCS would cause significant problems during such a large operation.

5.3.2 In the event, in excess of 6,000 items were recovered of which over 800 were munitions from an area of some 130 ha. Fortunately, most the ground was reasonably flat and had been recently been farmed so deployment and movement between digging sites was relatively straightforward. Each VCS needed 6-8 men to move it and a total of six units were used and deployed at the same time with teams digging in three different areas of the site. Thus each of the three areas had two VCS, one being moved whilst the other was being used to cover an excavation. Each work area had a cross country capable forklift truck for moving the AFUs, four for each VCS with four standby units in each area ready for use in the event of a phosgene release.

5.3.3 This method worked well but was hard work and was very manpower intensive. For future large area clearances for which the VCS is being considered it may be worthwhile to develop a towed sled or trailer mounted frame to ease movement across the site.

5.3.4 One unexpected advantage of using the VCS was the protection provided from the weather for troops carrying out the excavations. This also helped with leak detection and the sealing and packaging of recovered munitions. This was important since the operation took place during the winter which was wetter than usual with most operational days having at least some rain. Snow was not a problem but high winds on one occasion damaged the envelopes overnight when there was no one in attendance. After this the envelopes were removed when not being deployed or otherwise kept under direct control.

5.3.5 The trials to measure heat build-up inside the small VCS indicated that this could be a problem in hot weather but the cool wet winter conditions of the operation precluded this and cooling units were not required.

6 Conclusions

6.1 The VCS concept, both large and small design, reduced to an acceptable level the effects of the chemical downwind hazard from a simulated functioned Livens projector filled with chlorine, a volatile CW agent.

6.2 The VCS (with a primary ballistic containment system (BCS) reduced the effects of noise, fragmentation and chemical downwind hazard, from a functioned Livens filled with 14 kg (30.86lb) of phosgene, to an acceptable level.

6.3 The small, but detectable, levels of chlorine and phosgene identified downwind of the small VCS was due to the breakdown of the minimal number of 4 AFUs used and not to leaks from the containment structure

6.4 No chlorine was detected from the AFUs or downwind of the large VCS due, almost certainly, to the ample capacity of the 10 units used.

6.5 The VCS (both sizes) will provide sufficient protection to enable chemical munitions of the type trialed to be recovered from public areas without exposing workers or the general public to harmful concentrations of toxic vapour.

6.6 High temperatures are a potential problem area especially for the small VCS in hot weather. Trials with commercially available cooling units were successful in managing the temperature rise to acceptable levels. The dark green colour of the prototype small VCS contributed to the high temperatures measured. The commercially produced units used for Operation Abbott were made from colourless material and did not suffer so much from heat build-up though admittedly the weather was cool.

6.7 The manual method of VCS deployment method worked well but was very manpower intensive. For future large area clearances for which the VCS is being considered it may be worthwhile to develop a towed sled or trailer mounted frame to ease movement across the site.

7 References

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